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AN OVERVIEW OF ADVANCED FIBER REINFORCED POLYMER COMPOSITES AND IT'S APPLICATIONS

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ABSTRACT

The world today is required advanced fiber-reinforced polymer composites for aerospace, transportation, space shuttle, commercial airlines, bicycles, electronic product and automobile sectors. It is used widely because of their easier availability cost effectiveness, better reproductively and better stability against moisture. It has high strength, toughness, corrosion resistance, light in weight and low cost. The aim of this review article is to find the constituents, properties, fabrication, and application of advanced fiber-reinforced polymer composite and better utilization of available sources. In addition, it presents the various composite properties and characterization of FRP. This paper is focusing on the importance of FRP in mechanical field and latest development in composites world.

KEYWORDS: Fiber, Reinforced, Polymer, Composites, Aerospace, Transportation, Fabrication & etc

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Original Article

INTRODUCTION

A composite material is made by combining two or more materials to form third materials that have a very different property. FRP composites were developed 80 years before. It has high strength, high stiffness, high elasticity, light in weight, corrosion resistance and low cost [1]. They are replacing the metal with many uses like automobile and aerospace industries. The FRP composites are classified are as i) Metal matrix composites (MMCs) ii) Polymers matrix composites (PMCs), iii) Ceramic matrix composites (CMCs) and iv) Carbon/carbon composites. The approximate maximum service temperature of PMCs, MMCs and CMCs are up to 250^{0}C, 600^{0}C and 1200^{0}C respectively [2-4]. A composite normally consists of matrix and a reinforcing phase. The discontinuous phase is usually harder and stronger than the continuous face and is called the enforcement, whereas the continuous face has termed the matrix [4]. The classification of Fiber Reinforced Polymer (FRP) composites are listed below.

Table 1: Classifications of FRP Composites [5]

Sl	Matrix Type	Fibre	Matrices
1	Polymer	E- Glass, S-Glass, Aramid(kevlar), Boron, Carbon (Graphite)	Epoxy, Polyimide, Polyester, Thermoplastics, Polysulfone
2	Metal	Alumina, Borsil, Boron Carbon (Graphite), Silicon Carbide,	Aluminium, Copper, Magnesium, Titanium
3	Ceramic	Alumina, Silicon Carbide, Silicon Nitride	Alumina, Glass-ceramic, Silicon carbide, Silicon nitride
4	Carbon	Carbon	Carbon

The broad applications of advanced FRPs are in the sports sectors, aircraft, and aerospace and in automobile sectors. Advanced composite materials are generally known as polymer matrix composite [6, 7]. The center of advanced materials in transport aircraft structures was established in 2003 [8]. The two basic segments of advanced composite material are i) Industrial composites and ii) Advanced polymer matrix composites. Industrial composite utilizes resin, polymer, epoxy etc. These materials along with curing agent like glass fiber are used in the production for producing industrial components and human good like auto bodies, piping, boats and other components. The advance FRP composite industries are utilized the high-performance resin system for high strength and high fiber reinforcement for sporting goods like golf, tennis and archery etc [9]. At present manual and automated process are used for making advanced composite parts for machinery and transportation equipment [10].

CONSTITUENTS

The solid and another constituent of composites that has higher strength and more rigidity is reinforcement. The major constituents of a fiber reinforced polymer (FRP) composites are reinforcing fiber, matrix, coupling agents, coating and fillers [11].

Fibers

Fibers are the principle load carrying members. They are stronger and stiffer than that it is used in a bulk form. It has strong molecular alignment and is in the shapes of very small crystals. Fibers occupy the largest volume fraction of the composite. The various types of fibers are-

Glass Fiber

The most common fiber used in PFRCs is the glass fiber. It has a low cost, high tensile strength, low chemical resistance and excellent insulating properties. The Glass fibers are two types- i) E-glass and ii) S-glass. The tensile strength of S-glass is 33% greater and the modulus of elasticity is 20% higher than of E-glass.

Carbon Fiber

Carbon fiber has high strength, high stiffness, and light weight. Carbon fibers are produced by polymeric fiber precursors. It is mostly applied to the aerospace industry. The tensile modulus of carbon fiber is from 207 GPa to 802 GPa.

Aramid Fibers

Aramid is made of carbon, hydrogen, oxygen, and nitrogen and is essentially an aromatic organic compound. It has low density, lightweight, vibration damping, and resistance to damage, high tensile strength, and low cost. The first polyaramid fiber is developed as Kevlar by Du Pont [12].

Boron Fibers

Boron fibers have a high tensile modulus range from 379 to 414 GPa. It has a large diameter so they are capable to withstand large compressive stress and excellent resistance to buckling.

Ceramic Fibers

Ceramic fibers like silicon carbide and aluminum oxide are mainly used with elevated temperature. They have high strength, high elastic modulus with high temperature and are free from environmental attack.

Tensile stress-strain of various fibers [11, 12] are given below.

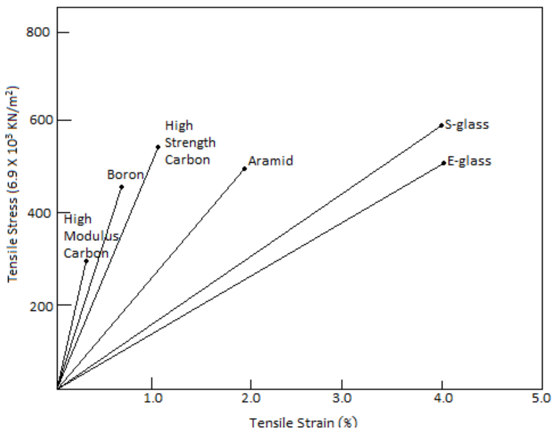

Figure 1: Stress Strain Curve of Fibers

Matrix

The matrix binds the fibers together, holding them aligned in the important stress direction. Matrix acts as the medium by which the load is transferred through the fibers by means of shear stress. Matrix protects the fiber from environmental damages caused by elevated temperature and humanity [13].

The different matrix materials are

Polymer Matrix Materials

It is light in weight and has desirable mechanical properties. Two types of polymer matrix materials are- a) Thermosets and b) Thermoplastics. Thermosets have 3D molecular structure after curing and are most suited for fiber composites. The main thermosetting polymers are an epoxy resin which is used in the aerospace structure for high-performance application, polyester resin, phenolic resin, vinyl ester resin and polyamides. Thermoplastics have one or two-dimensional molecular structure and soften at elevated temperature.

Metal Matrix Materials

Metal matrices have higher strength, fracture toughness, and stiffness. Titanium, aluminum, and magnesium are the main metal matrix materials.

Ceramic Matrix Materials

It has ionic bonding and covalent bonding and also has a high melting point, corrosion resistance, and high compressive strength.

Carbon Matrix Materials

They have highly superior matrix materials that sustain high temperature with strength and rigidity and not affected by temperature up to 2300^{0}C [14].

Coupling Agents and Prepregs

Coupling agents applied to the fibers improve their wettings with the matrix and also facilitate bonding across the fiber matrix interface. If fiber and matrix were available commercially as one entity, it avoids the procurements of the fiber

and matrix separately. Partly cured matrix resins act as a binder to a well laid out of fibers system. These fibers are known as prepregs [15].

Fillers

Fillers are added to the polymer matrix to reduce the cost, increase of modulus, control of viscosity and production of the smoother surface. The common filler in polyesters and vinyl ester resins is calcium carbonate. Clay, mica, and glass microspheres are common fillers [16].

PROPERTIES AND CHARACTERISTICS

The properties of FRP composite provide a basis for describing its behavior under various conditions. The physical properties of FRP composites are those characteristics that are used to describe a substance in the absence of any mechanical force [17].

Table 2: Properties of Some Typical Unidirectional Composite Materials [23-24]

Sl	Material	Fiber Volume Fraction	Specific Gravity	Young's modulus (GPa)	Shear modulus (GPa)	Tensile strength (MPa)	Compre-ssive Strength (MPa)	Shear strength (MPa)	Specific Young's modulus	Specific tensile strength	Longitudinal thermal expansion coefficient (10^{-6}/°C)	Longitudinal moisture expansion coefficient
1.	E-glass polyester (CSM)	0.18	1.5	8	3	100	140	75	5.3	67	30	0
2.	E-glass polyester	0.43	1.8	30	3.5	750	600	-	16.7	417	-	0
3.	E-glass epoxy	0.55	2.10	39	3.8	1080	620	89	15	514	7	0
4.	S-glass epoxy	0.50	2.00	43	4.5	1280	690	69	21.5	640	5	0
5.	Carbon epoxy (high modulus)	0.62	1.70	300	20	700	650	-	176	412	-	-
6.	Carbon epoxy (high strength)	0.62	1.60	140	15	1500	0	-	87	937	-0.9	0.01
7.	Kevlar epoxy	0.60	1.38	87	2.2	1280	335	49	63	927	-2	0
8.	Graphite epoxy	0.57	1.59	294	4.9	589	491	49	140	370	-0.1	0
9.	Boron epoxy	0.50	2.03	201	5.4	1380	1600	62	99	680	6.1	0
10.	Mild steel	-	7.8	207	8.0	325	340	190	26.5	42	12	0

The thermal properties of FRP composite are the thermal conductivity; thermal expansion and heat distribution temperature Thermal conductivity of a material is the rate of heat flow through it. The materials expanded when heated and contract when cooled [18]. The rate of expansion is governed by the bond strength and the atomic packing. The heat distortion temperature is a measure of the maximum service temperature for a plastic beyond which significant bending occurs [19]. The electrical properties are the conductivity. The electrical conductivity of a material represents the ease with which it can conduct electrical current. Ceramic insulator materials are often used as dielectric materials due to their good dielectric properties [20]. Polymer materials have poor conductivity due to lack of charge carries. Mechanical properties of composites are defining the behavior of materials under the application of mechanical force. It includes the strength, stiffness, ductility, hardness, fatigue strength, creeps strength and wears resistance of composites. The characteristics of the composite relating to its behavior in chemical reactions are called chemical properties of composite [21, 22].

NEEDS OF ADVANCED FRP

The first advanced composite material was the fiberglass and it is widely used at present for boat hulls, building panels, sports. Fiber reinforced composites have high strength and stiffness [25]. Coefficients of thermal expansions of fibers reinforced composites are much lower than those of metals. As such composites structure exhibit a better

dimensional stability over a wide range of temperature variation. Therefore the difference in thermal expansions between metals and composite materials create undue thermal stresses when they are used as a conjunction [26]. Fibers reinforced composites possess high internal damping. This leads to better Vibrational energy absorption within the material and results in a reduced transmission of noise, vibration, and hardness [27]. Polymers matrix composites absorb moisture from the surroundings which create dimensional changes as well as adverse internal stresses in the material. FRP constructions have a low maintenance cost. Structures made of fiber reinforced composite are lighter than those are made of conventional materials which reduce the weight and cost of materials [28].

APPLICATIONS

Commercial and industrial applications of FRP composites are diverse. The application of composites is on ships, submarines, aircrafts, trucks and rail vehicles, automobiles, robots, civil engineering structure, and devices etc. The applications of FRP composites [29-39] are broadly classified as -i) Automotive field ii) Aircraft and space iii) Marine field iv) sportive goods.

Application in Automotive Fields

Fiber reinforced polymers have been used in making the car parts like the exterior parts of the car such as door panels, hood are required sufficient stiffness and maximum resistant to dent formation, good surface finish, reducing the weight and increases fuel efficiency[30]. In the racing car the engine parts are made of graphite epoxy. Connecting roads are also made of composites for better performance. The other engine parts like push roads, rocker arms, pistons, cylinder leads and engine blocks are also made of composites to reduce the weight and to help for producing of more powers [32].

Application in Aircraft and Space

Aircraft are required reduction in weight to find the greater speed. Fiber reinforced composite has been found to be ideal for this purpose. Carbon fiber with a hybrid condition is used for making large numbers of aircraft components. Carbon and Kevlar materials are used for making wings, fuselage, empennage components, elevator face sheets, horizontal stabilizers and upper rudder etc. of commercial aircraft. Epoxy resin with FRP is used for making of helicopter blades. A missile structure, when made of FRP is light in weight and increased its range of action [30, 31]. Graphite composites are used for its high stiffness, strength and minimum weight. Graphite and Kevlar fibers are well suited for space allocations because of their high specific strength and modulus and low coefficient of thermal expansion. Strength and stiffness of composite material are the major consideration for the aircraft and low coefficient of thermal expansions and high stiffness are the major consideration for space applications. Antennas, booms, support trusses and struts of spacecraft, all are made by FRPs [33, 34].

Application in Marine Fields

Glass reinforced plastics (GRP) are used for making parts of boat hulls and yachts, dinghies, canoes, speed boats and passenger launches. GRP is low in cost, low maintenance cost and aesthetics [10]. GRP used in military and commercially hovercrafts. Hybrid glass reduces the hulls weights for construction of hydrofoils and fast petrol boats. Ultra high-performance sailing craft and power boats have advanced composite construction [34, 35]. Naval application of FRP includes weapon enclosures, gun enclosures, rudders, dry dock shelters, blast shields, missiles, ladders, deck drains, radomes, masts, and stacks. Marine applications of FRP also includes submarine casings and appendages, a superstructure

of ships, warship radomes, sonar domes, ship's piping and ventilation systems, oil and water storage tanks, floats and buoys for fishing and mine sweeping purpose[36].

Applications in Sporting Goods

Sporting goods are made of FRPs which reduces the weight of materials. Snow skis and tennis rackets are made of FRP with carbon and boron fibers which reduce the weight without degreasing of its stiffness. Fishing roads, bicycle frames, archery bows, sailboats and kayaks, oars, paddles, canoe hulls, racket balls, rackets, javelins, helmets, hockey sticks, athletic shoe, and heels are also made with help of fiber reinforced polymers [37-39].

FABRICATION METHODS

The fabrication method selected by a manufacturer depends on factors such as shape, cost, number of components and required performance. The various methods are-

Hand Lay-Up

In this process the fibers are placed in a mold. The fibers are in the form of woven, stitched or bonded fabrics and then resign is impregnated for forcing the resign inside the fabric [39]. The laminated fabrics are cured under atmospheric standards. This process is useful or the fabrication of wind turbine, boats, and archery moldings [40].

Spray Lay-Up

In this process, the fiber is chopped in handheld gun and fed into a spray of resin direct at the mold and deposited materials are left to cure under atmospheric conditions [41]. The polyester resin is used with glass roving for spray lay-up process. This process is used for light loaded structure panels, caravan bodies, bath tubes, truck firings, shower trays, etc [42].

Autoclave Curing

It is a closed vessel to control the temperature and pressure to use for curing polymer matrix composites. The cured composite is prepared by hand layup which has been impregnated with resin and then composite is placed in an autoclave after curing the composite is solidified [43]. This process is used for aerospace, automobile parts, bumpers, chassis, etc.

Filament Welding

It is an automated process and used for fabrication of structure or components. It is made of flexible fiber. This process is used for circular, hollow and oval section components. Fiber tows are wound onto a mandrel through a resin bath and wound component is then cured in an autoclave or oven and form creel into a fabric form [44]. This process is used for rocket motor casing, pressure bottle, chemical storage tank, pipelines, fire-fighters, gas cylinders, breathing tanks, etc.

Pultrusion

Pultrusion is a continuous process where the composites in the form of fabric or fibers are pulled out through a bath of a liquid resin and then pulled through a heated die. Finally, the materials are cured to its final shape and final product and cut it into a required shape. The resin-like polyester, epoxy, and phenolic may be used with ant fiber.

This process is used for making the beams and girders which used in the roof structure, ladders, bridges, frameworks, etc [45].

CONCLUSIONS

Fiber reinforced polymer composites have low density, high strength, low price and solidified easily as compared to synthetic composite materials. So FRP utilizes in construction and building materials, automotive industries, aircraft, space, marine field and other commercial applications. FRP composite improves the mechanical behavior of polymers. This article evaluates the properties and characteristics of FRP composites like energy absorption, thermal and mechanical properties, tribology properties, relaxation and viscoelastic behavior etc. Different fabrication methods of FRP are compared by the easiest way of fabrication with various applications. Finally, it is focusing on the importance of FRP in the mechanical field and latest development in composites world.

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